A COMPENDIUM OF HANDS-ON SOLAR WORKSHOP EXPERIENCES

THE SOLAR GREENHOUSE OUTREACH PROGRAM

FINAL REPORT

BY BILL AND SUSAN YANDA

UNITED STATES DEPARTMENT OF AGRICULTURE· RURAL DEVELOPMENT SERVICES

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INTRODUCTION

The United States Department of Agriculture (USDA) Rural Development Service (RDS) Solar Greenhouse Outreach Program was designed to expand the solar greenhouse concept through the format of "hands-on" workshops developed in New Mexico by the Solar Sustenance Project. The primary goals of the program were:

1) Work through existing public sector agencies to train housing and winterization crews in the design and construction of solar greenhouses.

2) Determine if the techniques proven to work in the western United States would meet with the same degree of participation and enthusiasm in other parts of the country.

3) Obtain hard data on greenhouse performance from various climatic zones.

The Outreach Project was handicapped in one sense, in that the contract was not signed with the USDA until September 26, 1977. A late fall start meant that there was very little time for an extended investigation and selection of community coordinators. The objective to build five greenhouses before winter set in was considered realistic if a north to south building pattern was followed. Help in contacting and selecting participant groups was given by the Community Services Agency and the RDS Washington offices.

Five sites were chosen:

1) Community Action of the Cape - Hyannis, Massachusetts.

2) Monticello Community Action Agency - Charlottesville, Virginia.

3) Murray State University, Center for Regional Services - Murray, Kentucky.

4) Low Income Housing Development Corporation - Durham, North Carolina.

5) Department of Local Services - Little Rock, Arkansas.

THE CONSTRUCTION WORKSHOPS AS A PROCESS

Each project must be considered a unique educational experience for the training team (contracted outside specialists) as well as the community coordinators (local sponsoring agencies or groups) and the participants. Before any workshop is begun it is beneficial for the separate entities to have a clear understanding of their duties and responsibilities.

TRAINING TEAM

Primary Duties:	Through:
Technical education	•Audio-Visual Materials •Field experience •Knowledge of reference work
Overall organization	•Close contact with community coordinators •Written guidelines giving problems and objectives.
Supervising building phase	•Leadership and participation
Follow up support	•Correspondence and consultation on specific problems

COMMUNITY COORDINATORS

Primary Duties:	Through:
Organization and coordination at the local level	•Arranging dates, facilities site •Securing necessary tools and materials •Publicity and invitations to participants •Serving as an information center after workshop is finished.

PARTICIPANTS

Primary Duties:	Through:
Build Greenhouse Receive training (if employed by sponsoring agency)	•Their labor •Attending all phases of workshop

PROJECT OWNER OR MANAGERS

Primary Duties:	Through:
Operation and maintenance of structure	•Managing greenhouse •Collecting and recording temperature and food production data •Making demonstration site available to the community for a specified time.

The community coordinators must have a format well in advance of the workshop in order to publicize the event, find a building site, order materials and reserve a meeting place for the evening lecture/multi media presentation. Within the structure of the workshop—lecture, design session, build, critique, follow-up—many options are available. If the structure of the workshop is not closely defined or limited, exciting possibilities for teaching and learning evolve. For instance, the building phase is a two day problem solving marathon which duplicates owner-builder construction situations. It is fairly easy to work from a professional quality blueprint and not encounter serious difficulties but this would be counter-productive to the overall goals of the workshop. Using the workshop as a *process* demands a different viewpoint and managing role by the project leaders. Each major building decision is open to explanation and group criticism. This means the training team should be prepared to explain and/or defend a particular construction technique or design against opposing views and, if necessary, change or compromise on the final product. A flexibility to adjust as you go is the reverse side of a "right way" in completely pre-designed applications. Examples of problem solving situations are found in every major step of the construction workshop. Local building techniques are usually responses to regional climatic conditions. A high water table near Charlottesville, Virginia, combined with an isolated demonstration site led the USDA outreach team into learning a new foundation technique—below grade pressure treated wood panels, an inexpensive and effective foundation for attached greenhouse structures. An ability by the leaders to read local sensitivities is crucial and can often determine the success or failure of the project.

IDENTIFYING DIFFERENCES BETWEEN PARTICIPANTS

There is a temptation (a dangerous one) to group workshop participants and their responses to workshop situations in an ethnic mode. However, closer examination reveals a less complex, and, perhaps, more accurate method of defining general grouping of participants, i.e., rural low income by plight or by preference; suburban, commercial, administrative, and those professionally involved in solar energy.

THE CHATHAM COUNTY HERALD, WEDNESDAY, NOVEMBER 16, 1977

4 gov't agencies sponsor solar greenhouse

'Let the sun shine in'

by Leslie Ware

Taking a drive along old 86, you may notice a small white house a few miles north of Pittsboro with a strange-looking structure attached to its side. Before you dismiss it as an unfinished room or a see-through garage, consider this: that structure, which is actually a solar greenhouse, will furnish up to 75 percent of the daytime heating needs of Mr. and Mrs. John Fearrington, who live in the house, and will provide space for $200-$300 worth of vegetable seeds. Furthermore, materials used in construction of the greenhouse cost only $700.

How did it get there? The answer lies in Bill and Susan Yanda. The Yandas are greenhouse experts who have built 53 of the solar greenhouses in various parts of the country. They have received a grant from the U.S. Department of Agriculture (USDA) to build five demonstration models, the fourth of which is the one attached to the Fearrington house.

The Fearringtons' solar greenhouse was built during two days of a three-day workshop, held Nov. 9-11,

himself. His initial investment was $25, but, unlike the Fearringtons', his greenhouse must be reglazed every year at a cost of $10-$12.

Meanwhile, daily readings are being taken of the extreme temperatures inside and outside the main house to determine the amount of energy saved by the greenhouse.

So far, says Dunham, the Fearringtons have been kept warm. "They said on Saturday--before the window was opened--they could hardly walk in the greenhouse it was so hot!"

But it will be another week before the temperature of the water in the barrels reaches 65 degrees and the plants are moved in.

How much interest is there in solar greenhouses? According to Dunham, a

Sometimes a participant fits more than one group, and often the training team will work with more than one group in a given project. The lecture/media presentation usually attracts people who desire analytical data, people who learn through listening or reading, those who are comfortable in lectures and seminars. At the building site participants will generally be those who want to take an idea and bring it into fruition themselves rather than hire someone to carry the idea through.

The local coordinators will set the tone of the workshop by the way they publicize and promote the event. They can quite accurately draw a particular section of the local citizenry if they focus attention and media spots to a target group. In this way, the workshop can be geared to a specific need in a community. If the workshop is sponsored by a Community Action Program the participants will mainly be winterization and weatherization crews. They will have experience in construction and will mainly be interested in design varieties and in becoming familiar with materials and techniques which are unique to greenhouses. On the other hand, the workshop held at a community college or university may draw participants well acquainted with design or engineering problems but unfamiliar with framing, glazing and insulating techniques. A good deal of time in this workshop mode is spent in teaching basic carpentry skills, tool handing and maintenance, and estimating material purchases. When the attendees at a program include commercial greenhouse growers the training team will need to address some practical passive solutions to retrofitting their structures. A commercial grower will have economic, spatial, and production considerations quite different than the home owner.

ACTIVITY TAKES PLACE AT ALL LEVELS IN THE WORKSHOP— CHARLOTTESVILLE, VIRGINIA

The one question which is always asked regardless of the make-up of the group is, "What will it cost me?" A full explanation gives the wide extent of costs ranging from a recycled materials unit which may be under $1.00 a square foot (owner built) to the professionally designed and contracted greenhouse which could be over $40.00 a square foot complete. In this project, the average materials cost were $5.21 a square foot. The training leader can explain that the final cost of a greenhouse is mainly a function of the prospective owner's aesthetics and not necessarily an accurate indicator of performance. An owner with the time commitment to spend in gathering recyclable materials, building, manually moving insulating panels, and carefully tending the plants can have as successful and productive a greenhouse as an expensive automated unit. A revolutionary aspect of solar greenhouse implementation is that high performance can be attained through human involvement. Unlike capital intensive systems, a greenhouse at either the community or individual dwelling scale is not dependent upon a constant input of capital or petrochemical energy. This makes the application available to all levels along the economic scale. However, people attending a workshop should be made aware of these options in order to have the information upon which to design a unit which fits their time commitments, performance criteria, aesthetics and budget.

CHARACTERISTICS OF EACH WORKSHOP SESSION

Each of the participating groups lent its own "style" to the project. Every session, and every greenhouse built as a result thereof, had certain strong and weak points. Rather than group them, it is educational to look at each separately. One unexpected and beneficial aspect of the project was that in several cases the Outreach Program acted as a focal point to bring diverse local agencies together in a cooperative effort to make the workshop successful.

COMMUNITY ACTION OF THE CAPE HYANNIS, MASSACHUSETTS

This agency, headed by Peter Olotka, has a variety of programs for senior citizens, low income families, health services, and a winterization program which has weatherized over 350 homes on the cape since 1976. The Outreach Program had severe time restraints but Mr. Olotka did a remarkable job of putting together the support elements of the workshop—money for materials, promotion, a building site with ten days' notice.

It was decided to locate the demonstration greenhouse on the Hyannis Community Club Annex. The Community Club is a non-profit citizens' group which rents facilities to the Community Action Program. It was felt that this location would be highly visible to the elderly and low-income clients of the sponsoring agency.

Three drawbacks to the site were noted and accepted at the time:

1) The unit does not have an ideal orientation. It faces east of south about 30^{o}.

2) Numerous trees, mostly deciduous, were too close to the collector glazing and would shade the greenhouse.

3) Because the greenhouse was basically on a public facility, certain problems in management and maintenance were bound to arise. This is a very important consideration and one which will be dealt with in more detail later.

STEP-BY-STEP PROBLEM SOLVING IS AN IMPORTANT PART OF THE CONSTRUCTION PHASE—HYANNIS, MASSACHUSETTS

SPIN-OFF WORKSHOP BY THE MASSACHUSETTS DEPARTMENT OF COMMUNITY AFFAIRS— MASHPEE, MASSACHUSETTS

The sponsoring agency and the director felt that advantages in exposure, immediacy and the experience of operating a solar greenhouse outweighed the drawbacks, so the decision to build there was made.

The evening lecture/slide show was attended by thirty members of the community including both paid and volunteer staff who would be working on the greenhouse.

The two-day construction period was attended by about twenty participants and several dozen onlookers dropped by. The first building day was covered by a constant drizzle. The rain picked up on the second day and work was halted at noon in a downpour. All structural components were completed but the agency was left with a great deal of finishing work. The greenhouse was finished by late November.

The greenhouse workshop at Hyannis was notable in several respects:

- It directly affected a state-wide solar greenhouse conference sponsored jointly by the Office of Energy Conservation and Resource Development and the Massachusetts Department of Community Affairs. At this intensive two-day session a construction workshop was organized and conducted by John Lavendier, a trainee at the Hyannis Workshop. It was quite successful and supports one of the primary goals of the USDA-RDS project.

- A grant of $5000 to build eight to ten greenhouses was given to Community Action of the Cape by the Massachusetts Department of Community Affairs. Community Action has sub-contracted the job to New Resource Group, Inc., (NRG), a local private firm whose personnel were also trained at the Hyannis Cape Workshop.

FINISHED GREENHOUSE—HYANNIS, MASSACHUSETTS

MONTICELLO COMMUNITY ACTION AGENCY CHARLOTTESVILLE, VIRGINIA

The next workshop in Charlottesville, Virginia, was in many ways similar to the first. The second workshop was scheduled to be in the high hills of western Maryland. Four days before beginning the project, it was unexpectedly cancelled by the local coordinators, leaving the Outreach Team with the only possible time slot in the next month and a half vacant.

The director was again very fortunate in finding Ken Ackerman, Director of the Monticello Community Action Program, an administrator who could move quickly and professionally in coordinating the local resources. Mr. Ackerman contacted Tom Hill of Albemarle County Home Improvement Program. AHIP is a county supported agency using primarily volunteer help. They weatherize and winterize homes of the elderly and rural poor.

Mr. Hill promised support in choosing a site, procuring some materials and making his student workers available. Ken Ackerman secured the majority of material money needed from the State Community Action Agency and also enlisted the enthusiastic aid of the Monticello C.A.P. community gardening personnel.

Quick publicity was needed so that citizens would know about the program. The Charlottesville Daily Progress helped with a half page article on the front of their Sunday Home Building section. That same evening, 110 people came to the presentation at the University of Virginia Architectural Hall. An examination of the registration list shows a high percentage of professional people; architects, engineers, professors along with a good representation of agricultural professionals; farm managers, florists and commercial greenhouse growers. This kind of response is typical of a solar greenhouse lecture if publicized well in advance. It's rather unusual on such short notice.

The demonstration site, chosen by Tom Hill, was at the home of Mr. & Mrs. James Sprouse. The site is the least visible or accessible in the project. It's about five miles outside of Charlottesville up in a hollow. The Sprouses are in their 80's and have lived in the log cabin since the early 1900's. The home has neither electricity nor indoor plumbing. Mr. Hill, with AHIP, had done extensive weatherization on the home over the last two years.

HOME: BUILT IN EARLY 1900'S BY MR. JAMES SPROUSE ~ GREENHOUSE: OCTOBER, 1978

There were several problems relating to the site:

•Mr. Sprouse, although he chops all the wood for heating the home, didn't want solar heating. It was out of his area of experience so he didn't trust it. Mrs. Sprouse and Tom Hill assured the director that they would convince Mr. Sprouse to change his mind. They did, and heat from the greenhouse was used during the winter.

•Since neither of the Sprouses read, it was impossible for them to collect data or read pertinent information on greenhouse management.

•Mrs. Sprouse has a great deal of gardening experience but viewed the greenhouse primarily as a flower growing area.

MRS. JAMES SPROUSE WITH SUSAN YANDA

The building took place on the Monday and Tuesday immediately following the Sunday evening lecture. The construction crew was composed primarily of young volunteers, students at the University of Virginia, from the AHIP building crew. (When workshops occur on weekdays the participants will generally *not* be a cross section of a community). In this case, the college-aged builders were trained in identifying potential solar greenhouse sites for their AHIP winterization work.

Because the site had neither running water (a small spring is the Sprouse's water supply), electricity nor adequate facilities for mixing concrete, a pressure treated wooden foundation was constructed. This technique is code approved for Virginia and much of the Southeast and offers a viable option for homeowners concerned with the cost or scarcity of concrete.

WATERPROOF WOODEN FOUNDATION BEING ASSEMBLED—CHARLOTTESVILLE, VIRGINIA

Rain was, again, a problem during the workshop. The second day ended with the greenhouse about 60 percent finished. AHIP completed the unit in the following month.

Afternote: In the spring, Mr. Sprouse had a stroke which was partially disabling. It will prohibit much of the woodcutting that he had done in the past. The small (120 sq. ft. greenhouse) can produce over 40 percent of the heating for the log cabin.

MURRAY STATE UNIVERSITY CENTER FOR REGIONAL SERVICES MURRAY, KENTUCKY

The Kentucky workshop indicates the potential for outreach projects to reach citizens when the local coordinator is given adequate lead time and support. The workshop, held in Murray, Kentucky, was coordinated by Ray Dunn, the director of the Center for Regional Services at Murray State University. Mr. Dunn had been in contact with the Rural Development Service before the outreach project began and was anxious to be a part of the solar greenhouse program. He had a month of lead time and used his organizational skills to schedule a week packed with four evenings of lecture/slide shows at Mayfield, Paducah, Clinton and in Murray. In addition, two radio interviews, one TV session, and a horticulture class at the building site were scheduled.

Ray Dunn coordinated the project with Western Kentucky Allied Services, an agency which, among its other services, winterizes homes in eight counties. This group provided the money for materials and also sent crew members from each county to learn solar greenhouse design and building techniques (about 30 builders in all). Also present were several employees of the Tennessee Valley Authority.

The greenhouse is on the home of Mrs. Ellen Hodges, a retired farming widow. Mrs. Hodges' house is adjacent to a main highway into Murray and quite visible. (So many people stopped to investigate during the building phase that the site was almost a safety hazard.)

MRS. ELLEN HODGES AND SON IN GREENHOUSE— MURRAY, KENTUCKY

Workshops by this time wouldn't feel complete without rain so nature obliged with a light, but steady drizzle. The emphasis was on teaching the winterization crews design and building techniques peculiar to solar greenhouse construction so that they could employ that knowledge in the field. The unit was 90 percent completed in the two days of building and the remaining 10 percent was finished by the end of the week including soil mixing, plant beds and some planting.

INTERIOR TRIM GOING UP—MURRAY, KENTUCKY

Important aspects of the Murray workshop were:

•The effects of adequate lead time and coordination were obvious. Mr. Dunn used a "barnstorming" or "take it out to the people" approach to promotion that brought citizens to the lectures from as far away as Jefferson City, Missouri.

•Because ample time could be scheduled the directors had an entire week to spend seeing through the completion of the building and working with Mrs. Hodges, the operator of the greenhouse. The extra time paid off—the best data collected came from the Murray greenhouse .(See temperature chart, page 16)

•There was considerable skepticism expressed by several faculty members at the state college and university about the concept or effectiveness of the solar greenhouse. It was felt that the simple low cost unit built could not possibly make it through a typical winter in that area without freezing. A quick examination of the data shows that the greenhouse did meet expectations in what local residents have described as "the coldest winter in a hundred years." The principles embodied in the Murray solar greenhouse (passive thermal storage, insulated north wall, etc.) could be used in the Murray High School greenhouse which presently is shut down in the fall and reopened in the spring because of high heating bills.

LOW INCOME HOUSING DEVELOPMENT CORPORATION DURHAM, NORTH CAROLINA

This workshop, held at Pittsboro, was the most ambitious combination of agencies in the project. Coordinated by Henry Gaither of the Low Income Housing Development Corporation of Durham, the two primary agencies hosting the project were the Joint Orange-Chatham Community Action, Inc., and the Chatham County Council on Aging. These groups, in turn, issued an invitation to all the CAP weatherization crews in the state to attend the workshop. Eighty-seven people were registered at a luncheon lecture/slide show on November 9. Besides the CAP Agency people attending, the lecture drew a broad cross section of interested citizens (professors from Tuskegee Institute in Alabama, city planners, architects, and some TVA employees).

The site chosen by John Huer of JOCCA and Bob Dunham of CCCOA is in Pittsboro, North Carolina on the home of Mr. and Mrs. John Henry Fearington, an elderly rural couple. It appeared to be ideal, but upon later investigation it was found shaded by some very tall pine trees to the south until about 11:00 a.m. on winter mornings.

The construction workshop had the greatest number of participants the director has ever worked with, and for once, the weather was excellent. Sixty-six people signed the registration list and just about all of them worked on the greenhouse. It should be noted that this is far too great a number of workers for a standard construction workshop. Normally the participants in the building phase on a small project should not exceed 25 or 30. The only reason this workshop maintained direction and order was that most of the participants had established crews used to working together. Also, the JOCCA and CCCOA coordinators did an outstanding job of support in terms of having materials, food and crew leaders prepared.

SOME OF THE 66 PARTICIPANTS OF THE NORTH CAROLINA WORKSHOP—PITTSBORO, NORTH CAROLINA

The end of the two-day session saw the greenhouse totally complete. Even a soil test had been completed by the Agronomic Division of the North Carolina Department of Agriculture.

This workshop demonstrated several things:

•With proper leadership and coordination it is possible to train large numbers of people in the "hands-on" format of the workshop. This leadership must come from the local level. It would probably fail if imposed from outside.

•An idea planted in this manner can quickly bear fruit. The Solar Outreach Team was asked by eight agencies at the session to come to their communities to run workshops. This was impossible, but participants have proceeded on their own and have managed 9 workshop programs since November 1977.

•Coordinators at the Pittsboro workshop utilized the media to maximum benefit. 'Live' reports from the building site were seen on the local news on two of the major television stations in the area. The entire process was taped for presentation on the Educational TV Service as part of a regular series. In this way, the impact of the greenhouse project went far beyond the direct participants in the program.

MRS. FEARINGTON AND SUSAN YANDA DISCUSS HORTICULTURE OF GREENHOUSE—PITTSBORO, NORTH CAROLINA

DEPARTMENT OF LOCAL SERVICES LITTLE ROCK, ARKANSAS

The last workshop in the Solar Outreach Project was held in Little Rock, Arkansas. It was coordinated by Mr. George Ivory of the State Department of Local Services. Mr. Ivory brought 30 administrative representatives of private and public housing agencies to a mid-day lecture and slide show. The building session was scheduled for the following two days at the Economic Opportunity Agency with attending employees of CAP weatherization crews from around the state.

PROPOSED SITE OF DEMONSTRATION UNIT—LITTLE ROCK, ARKANSAS

The site, the E.O.A. building, presented some insurmountable problems. Here, it is necessary to note an inherent weakness in the Outreach Program as it was conducted. All pre-workshop communication between the directors and the local coordinators was by phone and mail. There was no time for site visits or interviews by the directors with the perspective operators. This placed the sole responsibility for the technical appropriateness of the site into the hands of the local coordinators who, in each case, had no training in solar energy or construction techniques. It was inevitable that a major obstacle to building would occur, as it did in Little Rock.

The proposed site was in the southwest corner of the E.O.A. building, a 3-story brick structure. Besides a poor solar orientation, the construction of the 16 foot greenhouse would have been hampered by an 18" wide concrete facia trim on the bricks which would make weatherproofing the solar addition almost impossible. It was realized by the local coordinators that the site wasn't ideal, but they hoped that the effect of the demonstration being on the E.O.A. central offices would spur interest in the field and outweigh the technical disadvantages. The decision not to build there was a difficult one for the director. All of the site preparation had been done (clearing small trees, leveling, foundation/block stem wall in, gravel on the floor) and twenty weatherization crew workers were ready and willing to start. If the workshop was scrapped, there would have been quite a few disappointed people in Arkansas. With the materials and participants on hand and a large flat parking lot for a work area, it was decided that a portable demonstration of the solar greenhouse could be built and made available to interested groups for educational purposes. A similar working sized model had been built for the New Mexico Energy Resources Board two years before and had been used quite successfully many times since them. (At this writing the model has been through three state fairs and, perhaps, a dozen energy fairs and seminars. It's been examined by over 10,000 citizens).

PORTABLE UNIT UNDER CONSTRUCTION—LITTLE ROCK, ARKANSAS

The model built in the remaining soggy day and a half contains all of the technical elements of the attached solar greenhouse, so the attendees did receive the training in design and site selection which they came to learn. The model is being used by the Economic Opportunity Agency and was on display in a downtown Little Rock Mall for two weeks in May of 1978.

Notable aspects of this workshop were:

•A flexibility to change plans on the spur of the moment is necessary for workshop leaders, even if arrangements are firm and all pre-workshop organization has been completed. For instance, all hands-on projects are subject to vagaries of the weather. When people from all over a state or region are assembled, it is no time to cancel and go home. Contingency plans for an indoor or alternate site should be made.

PORTABLE GREENHOUSE COMPLETED—LITTLE ROCK, ARKANSAS

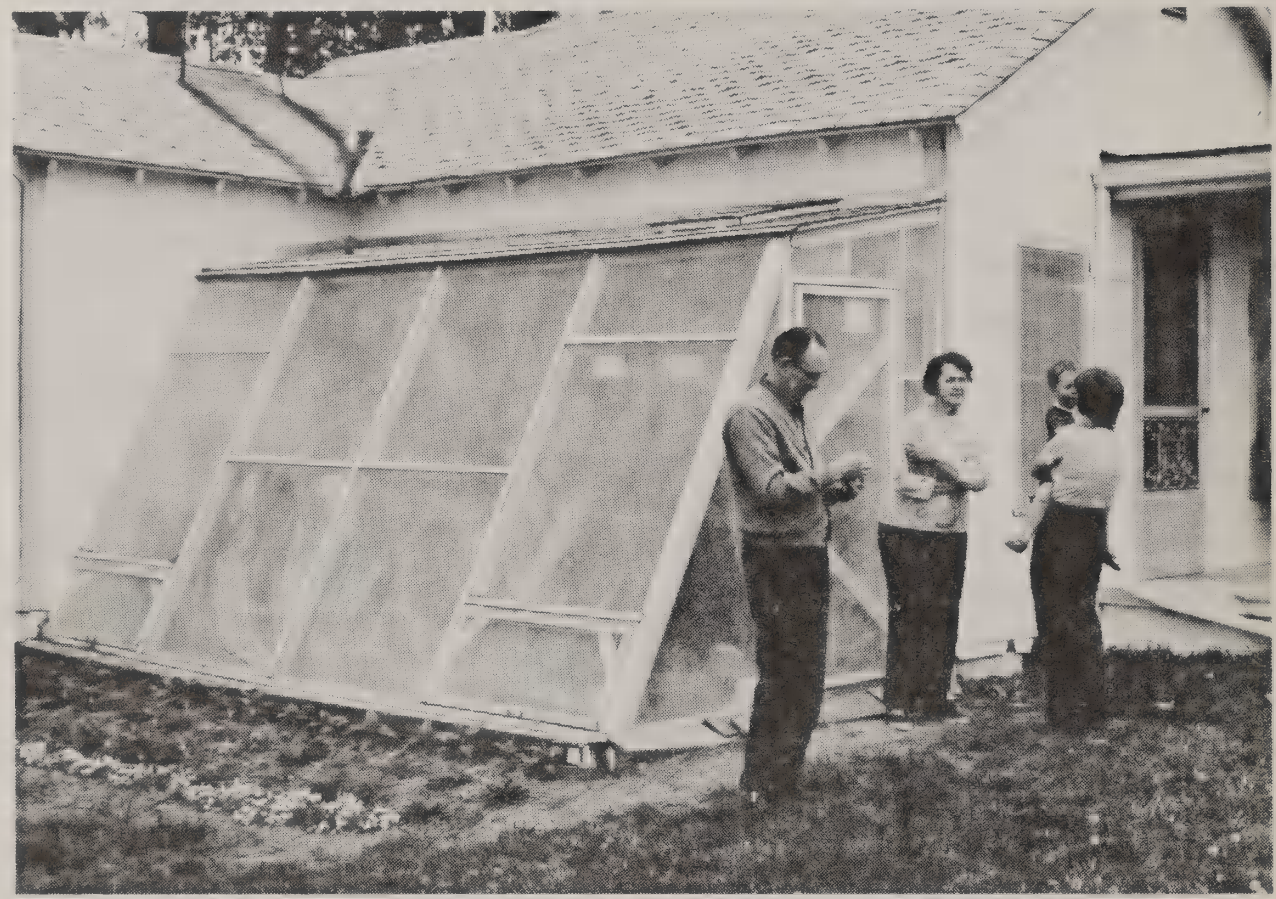
•Ideally, local coordinators or someone in their team should have a basic solar and construction technical understanding to choose the best possible site for the demonstration. The Little Rock workshop achieved its goals despite some initial handicaps .(See Ozark Institute, page 19)

THERMAL PERFORMANCES IN THREE AREAS

The following charts and data were collected from three different sources. It must be noted that data gathering in the solar greenhouse field is in its very earliest stages and the equipment used to monitor most units is no more than hi-low thermometers. To compound the problem, the greenhouse, because it is occupied by both plants and people, is a much more complex system than a flat plate solar collector or a Trombe wall. Actual performance is a function of many overlapping factors (when vents, windows and doors are open, how much time the operator is spending in the greenhouse, what amount of watering is done, etc.). Also, it must be remembered that the Murray, Kentucky and Midland, Michigan units were built late in the fall. The interior thermal mass carried no 'charge' into the winter. Under regular operating conditions, it could be expected that the greenhouses will run somewhat warmer. With all these, and many other factors in mind, we can examine recorded and predicted performance in several areas of the country.

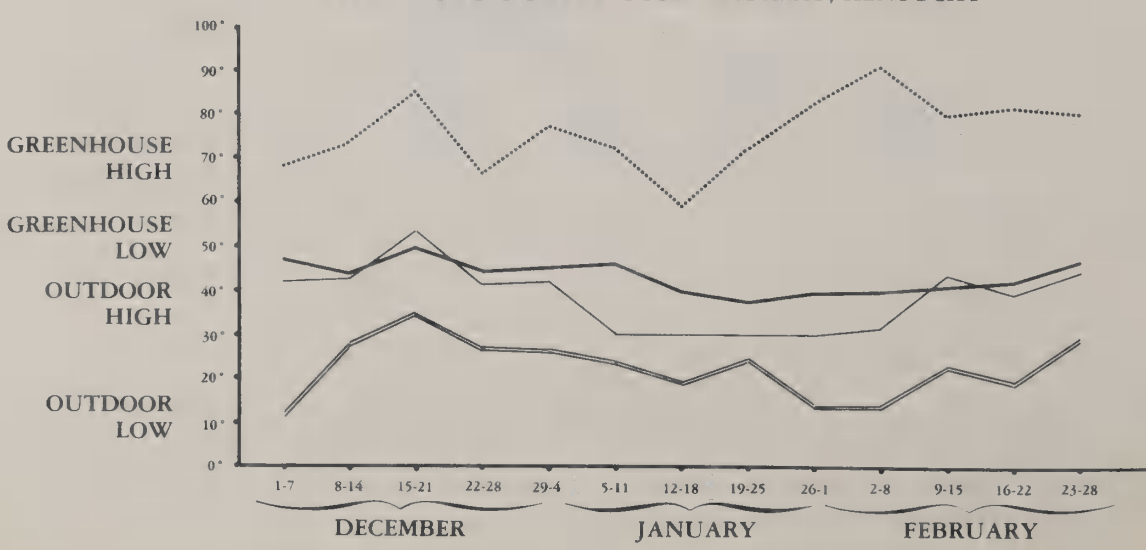
MURRAY, KENTUCKY

The data collected was from two high-low thermometers. Mrs. Hodges, the greenhouse owner, also recorded the weather conditions for each day. Her observations match the temperatures in the greenhouse, i.e., on a clear day regardless of outside temperatures the greenhouse would achieve 80+. A partly cloudy day would produce interior temperatures in the 70-80^{0} range. A totally overcast day would result in high temperatures of 50-70^{0} in the greenhouse.



EXTERIOR HODGES GREENHOUSE—MURRAY, KENTUCKY

WEEKLY SOLAR GREENHOUSE TEMPERATURES
December-January-February
1978
ELLEN HODGES GREENHOUSE — MURRAY, KENTUCKY



Several important aspects should be noted:

•On December 26, Mrs. Hodges first observed that the north wall of the adjacent room (the one receiving the heated air from the greenhouse) became wet. The humid heated air from the greenhouse met a cold uninsulated wall surface and condensation was occurring. This is the first time in over 50 greenhouse retrofits that the addition has resulted in this problem. It is the fault of the director and illustrated an important point to check before a greenhouse addition is planned: the room on which a greenhouse is built *must* be well insulated. It is expected that the wall will be insulated before this winter and the problem will be solved.

•Using the 75°+ daily temperatures as periods when the greenhouse would be providing the adjoining home with some heat we find that heat is available:

19 days in December

15 days in January

18 days in February

This does not mean that heat would always be available throughout the entire day. On the clear days (80°+) it would probably be charging the house from 10:00 a.m. through 5:00 p.m.

•95° days are common in late January and February. They show that Mrs. Hodges was not using the greenhouse to heat the adjoining room (because of the condensation problem) and, as a result, the greenhouse is overheating:

While the low tempeatures recorded are too cold for fruiting vegetables, they are at the low end of the acceptable range for leafy greens and cold tolerant crops. A simple I.R. reflective drape on the inside of the greenhouse drawn at night would raise the interior temperatures about 10°F.

CHIPPEWA NATURE CENTER MIDLAND, MICHIGAN

The greenhouse at the Chippewa Nature Center in Michigan was built under private contract in a workshop by the directors shortly before beginning the USDA Project. It is interesting to observe because it gives us a hard case situation for any solar application. Midland, in the center of the lower Michigan Peninsula, has solar and degree day conditions worse than almost any place in the contiguous United States (and poorer than many Canadian locations farther north). The moisture laden air off of Lake Michigan to the west creates heavy overcast skies from late October to January, and the degree days are in the 8000 range.

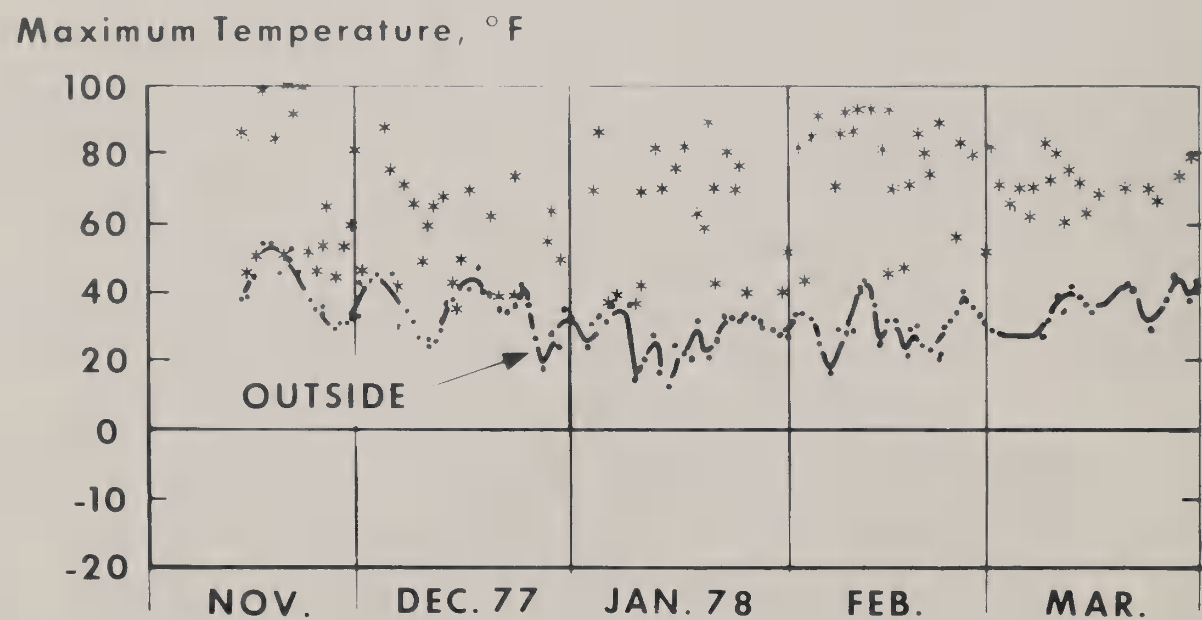
CHIPPEWA NATURE CENTER GREENHOUSE. NOTE EXTERIOR INSULATING AND REFLECTIVE PANELS—MIDLAND, MICHIGAN

•The greenhouse (10 x 20') was built adjacent to an old barn. The wall between greenhouse and barn was poorly insulated and temperatures inside the barn approach ambient outdoor temperatures. The heat loss through the greenhouse to the barn is high compared to a regular home/greenhouse combination. It is estimated that interior greenhouse temperatures will be 5 to 8^{0} higher, both day and night, when the wall is well insulated.

•Removeable exterior shutters of 2" Styrofoam were applied to the large south face in the evening and removed in the morning. This was not an optimal insulating scheme, but was the best that could be arranged at the time with available labor and finances. The entire greenhouse was rather "loose," that is, not well sealed, for its first winter's operation. In the interim, sealing and insulating has been accomplished and an airlock added to the western wall of the structure.

Given the unfinished quality of the greenhouse the C.N.C. staff recorded the following maximum temperatures in the greenhouse:

MAXIMUM TEMPERATURE OF CNC SOLAR GREENHOUSE



Using the 75^{0}+ temperature criteria we find that the greenhouse could supply heat to the adjoining building:

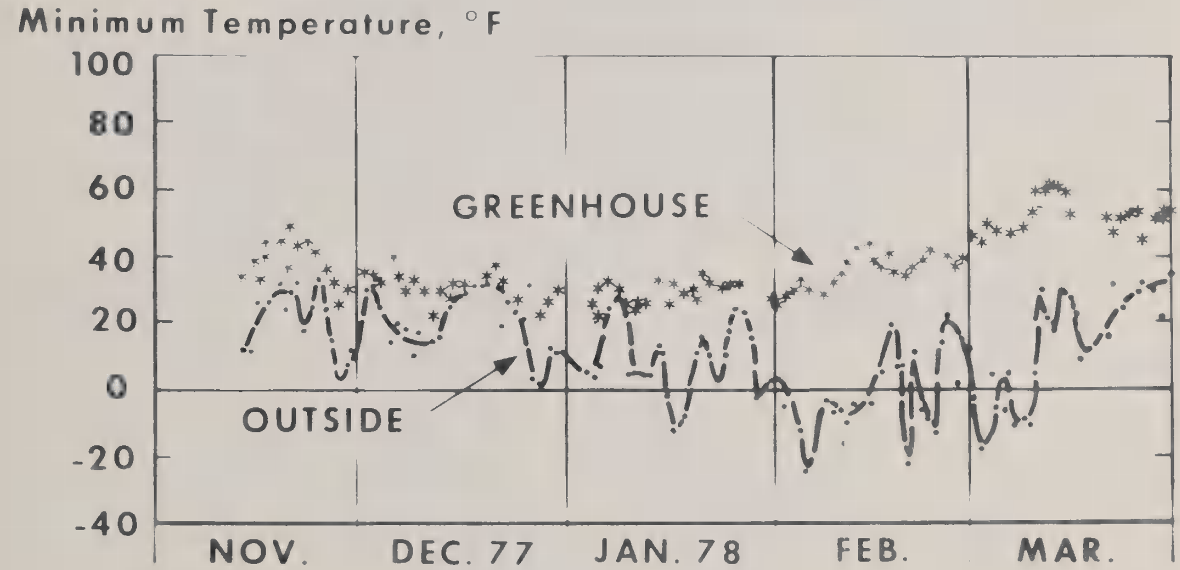
6 days from mid-November
5 days in December
7 days in January
19 days in February
10 days in March

It is a safe assumption that sealing the structure better and insulating the north wall would raise the temperatures considerably. If a 6-8^{0} rise was the result, the greenhouse would have heat to give on:

6 days from mid-November
9 days in December
13 days in January
19 days in February
19 days in March

Low temperatures were in the near freezing 33-35^{0} and freezing range all through late November, December and January but began a slow, but constant climb back up the scale in early February when outdoor lows occasionally cimbed up to 0^{0} or above.

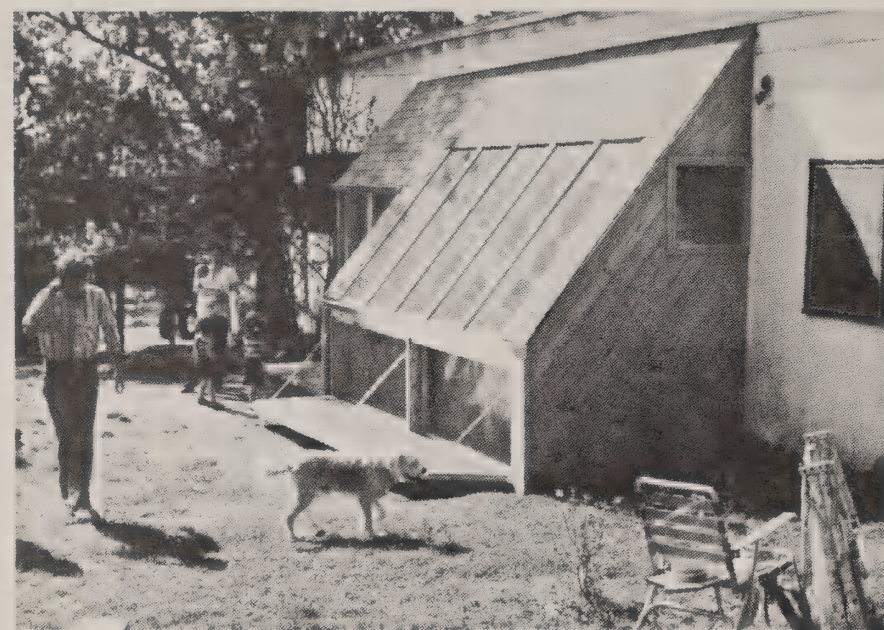
MINIMUM TEMPERATURE OF CNC SOLAR GREENHOUSE



Looking at the data, one becomes aware that this greenhouse in its 77-78 status will not grow anything from late November to mid-February. However, the staff at the Nature Center was not discouraged by the first winter's performance. They have completed the finishing work mentioned above and are anticipating vast improvements for the second season. They also report 20-30 'spin-offs,' owner built and financed greenhouses, as a direct result of the workshop, and they sponsored the Great Lakes Solar Greenhouse Conference in October 1978.

BERRYVILLE, ARKANSAS

The Berryville, Arkansas solar greenhouse is an outstanding example of the 'spin-off' the Solar Outreach program achieved. The Ozark Institute, headed by Edd Jeffords, sent Bill O'Neill to the Little Rock workshop to get technical training and practical experience. Mr. O'Neill went back to Eureka Springs as the solar project director and, with Albert Skiles, designed and built the Berryville greenhouse and two others. The Institute had received a $1,000 grant for one greenhouse. By recycling materials and careful purchasing, they built three greenhouses for that amount.



GREENHOUSE BUILT BY OZARK INSTITUTE—BERRYVILLE, ARKANSAS

From Mr. Skiles Report for the Office of Human Concern in Arkansas:

"Two such greenhouses were recently built onto the homes of J.D. and Dorothy Trahan of Madison County and John and Coleen Strandquist of Carroll County. Winter heat gain will be more efficient than conventional designs because of a reflective-insulative shutter along the vertical South wall. Open while the sun is shining, the shutter will admit about 30 percent more solar energy onto storage containers within the structure. At night the shutter is closed to greatly reduce heat loss.

"The glass panes on the South wall (see photo above) are removeable to control heat during hot, humid periods. Prevailing South breezes can then enter through a continuous fixed screen. This gives the greenhouse a generous vent to floor ratio of 1:2. The glass panels can easily be replaced the next fall in an airtight manner.

"The Trahan greenhouse has a thermostatically controlled blower near the ceiling which will deliver heat (on at 110°—off at 90°) to the house whenever it becomes available. By attaching a meter in the circuit, we can accurately determine how much surplus heat is produced by the greenhouse.

"The Standquist greenhouse will be connected directly to the living space with no dividing wall. Heat gain to the house will be found by comparing the fuel cost per degree-day ratio with those of previous winters."

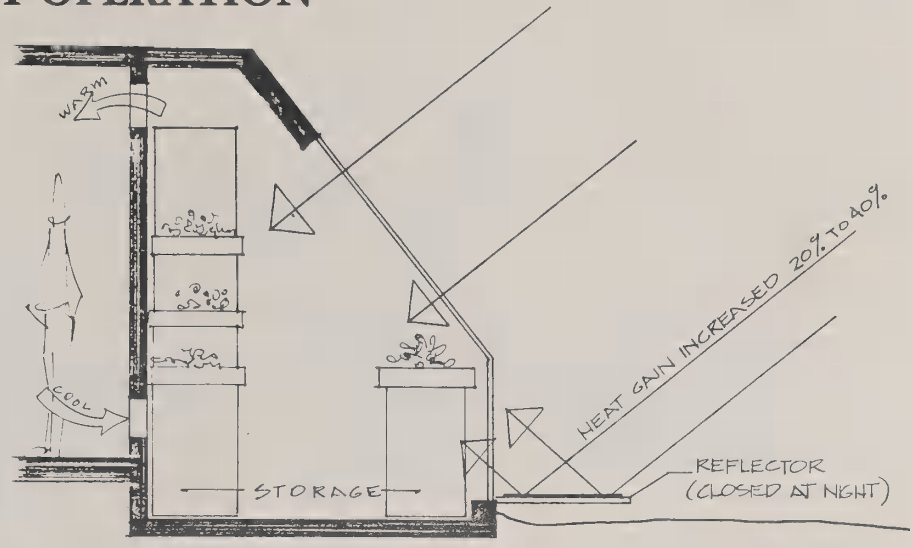
NORTHWEST ARKANSAS SOLAR DATA
FROM CLIMATIC ATLAS OF THE UNITED STATES U.S. DEPARTMENT OF COMMERCE

Heating Season — October to April

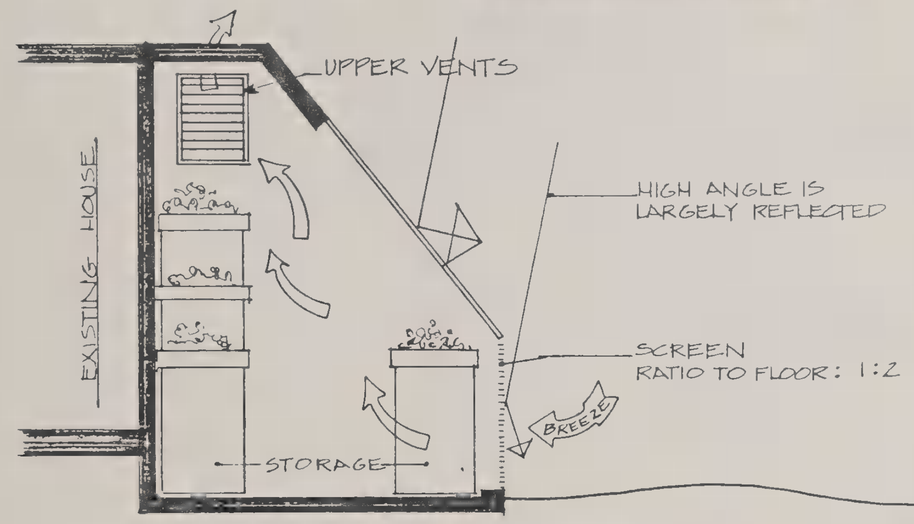
Month	Av. Temp.	Degree Days	Horizontal BTU/ft.^{2}	South 60° BTU/ft.^{2}	Ave. Min. Temp.
OCT.	62	93	40,036	52,046	50
NOV.	48	572	27,675	49,815	35
DEC.	40	775	20,018	44,039	28
JAN.	38	837	20,000	44,000	25
FEB.	40	725	26,863	48,353	30
MAR.	48	527	41,180	53,534	36
APR.	58	210	51,475	51,475	48
		Total available solar energy at a 60° south tilt:		343,262	
			Loss through glass:	x .80	
				274,609 BTU/ft.^{2}	

PRINCIPLES OF OPERATION

WINTER



SUMMER



TRAHAN GREENHOUSE

Size — 8' x 15' — Door on east side

Storage — Fifteen 55 gallon black barrels - 825 gallon total will exchange 6848 BTU per degree F

Winter Heat Loss - 30^{o} average temperature difference

	Area ft.^{2}	R-Value	ΔT	Heat Loss—BTU/hr.
Floor	120	10	30	360
Glass	100	7	30	245
Edge	32	17	30	56
Infiltrat.				100
Wall & ceiling	204	25	30	244
				1,005 - Heat loss per hour
				x 24 - Hrs.
				x 212 - Days in season
				5,113,440 BTU - Total for season

Heat Gain 27,460,900 BTU
Heat Loss 5,113,440 BTU
Surplus 22,347,460 BTU — 6545 KW Hrs. at 5 cents — $327.28

The designs show a sensitivity to local climatic conditions (e.g., removable glass panels for hot and humid weather), which reinforce the conclusions of the Outreach Project.

"Data charts and temperature sensors will be provided each family to assure accurate documentation. At the end of the 1978-9 heating season, information will be compiled and distributed to the public by the Ozark Institute."

CONCLUSIONS, SUGGESTIONS, RECOMMENDATIONS

The USDA-RDS Solar Greenhouse Outreach Project achieved its first two goals and fell short of the third. Documented attendance and interest by people in both the public and private sectors demonstrated their desire, to learn inexpensive and multifunctional applications of solar energy such as the solar greenhouse concept. Without exception, a "ripple effect" is evident. Every agency worked with is currently engaged in or is planning solar workshops at this writing. Private sector building has also been spurred in the solar greenhouse field by the project although the exact amount is impossible to determine in the limited scope of this short program. Every locale in the project can document several examples of private building by attendees to their workshop.

Reasons for the shortcoming on data collection are to be found in the suggestions and recommendations listed below.

The weakest point in a program of this nature is the follow-up activity. (There are about a dozen 'hands-on' solar training groups in the U.S. now who can verify the correctness of this statement.) Follow-up, in this sense, should include both monitoring data and continued training of the unit operators. To date, leaders in the field of hands-on solar training have been so busy teaching people the technical aspects and building techniques used in solar applications that they have not adequately provided follow-up data or support to the demonstrations they have built. Commonly, a contract for a project like this will run for a one year or shorter period. This is not nearly long enough for any substantial data from a solar greenhouse project. For instance, the temperature records from the Murray and Michigan units represent a winter which is acknowledged to be one of the coldest on record. We should have 'worst case' situations. A 'typical' Murray winter would show the temperature profile of the greenhouse to be entirely different. Therefore, a prediction of performance using average yearly data is probably more accurate than the recorded data in any one period. Another area which lacks data or is easily misinterpreted is the food production of a small greenhouse. Almost all the emphasis on food production in greenhouses has been directed toward large scale mono-crop commercial units. The relevance to the small scale, multi-crop, organically operated greenhouse is practically non-existent. To expect similar performance and management techniques to come from short term projects is not realistic. To date, research published about summer gardens is more relevant to the small scale greenhouse than in the research published about conventional greenhouses. The small-scale, food-producing greenhouse is new ground; totally new territory in agricultural potential.

Who then is prepared to experiment and evaluate results in this field? It is our suggestion that this expertise can only come from the local level. Follow-up in aiding the new greenhouse gardener is extremely important and is best served by the local agricultural extension agent or community garden expert within the horticultural and climatological zone of the site. Experience with Solar Sustenance greenhouses built in 1974-75 indicates that it can take as long as two years for the greenhouse owner to experience success in gardening indoors. Without proper training and access to information, the time frame could be longer. (Hence, the number of solar greenhouses built both publicly and privately which do not show the results of other well published and better known units). The fault is not with the greenhouse, it is with the educational processes on which the greenhouse is dependent.

A program to obtain quantified information on solar greenhouses has just been undertaken by Andy Shapiro of the Technical Research Staff of National Center for Appropriate Technology (NCAT). Twenty greenhouses in New England will be monitored on a daily basis for a one year period. Attached greenhouses will be considered only if the fuel usage for the home from the previous year is known. Volunteers, who have the knowledge and desire to spend the daily time necessary to record the data on the form below, will be selected.

NCAT SOLAR GREENHOUSE DATA SHEET—THERMAL

Greenhouse Name ______________________

(1)	Date							
(2)	Time							
(3)	Name of person taking data							
(4)	Greenhouse Interior	Temp						
(5)		Max						
(6)		Min						
(7)	Outdoor	Temp						
(8)		Max						
(9)		Min						
(10)	Soil Temp							
(11)	Storage Temp	A						
(12)		B						
(13)	% of sun yesterday							
(14)	Wind-see instructions for estimating guide							
(15)	Was glazing insulated last night?							
(16)	Amount of back-up used							
(17)	Number of hrs. Vents (V), Doors (D), Fans (F), used yesterday							
*(18)	Number of hrs. heat taken from greenhouse to building yesterday							
*(19)	Number hrs. heat taken from house to greenhouse yesterday							
(20)	Fuel bills for house							
(21)	Comments-(thermal and structural) (Changes in greenhouse, materials performance, snow, shading, and whatever else.)							

*For attached greenhouses only

NCAT SOLAR GREENHOUSE DATA SHEET—HORTICULTURAL

Greenhouse Name ______________________

Date								
Quantity watered	(time)							
Water temp ____ °F	min.							
Flow rate ____ gal./min.	gal.							
Fertilizing (Quantity and type)								
Area of seed (S) or transplant (T) planted, area (ft^2) each variety, and number of transplants								
Grams of crops harvested - variety and partial (P) or final (F) harvest								
Pest and disease incidence and control								
Hours worked in greenhouse								
Operating expenses								
Income								
Comments - horticultural and organizational (stages of growth, plant responses, CO_2, problems, changes in technique, daily maintenance, lighting, lifestyle effects, and ANYTHING ELSE).								

In order to receive the monitoring instrument package and be part of the program, applicants must fill out a detailed ten page form on the technical specifications of their home heating system, ventilation, recorded fuel usage, greenhouse design, gardening experience and the like. It is suggested that this one year monitoring program is superior to methods used in construction/demonstration projects and should yield valuable hard data.

Another solution to this problem is already well along. As more solar greenhouses are built, there is more regional experience in building and operating them. Regional and national conferences such as the Marboro Conference in November 1977 and the recent Great Lakes Solar Greenhouse Conference in October 1978 bring interested parties together and help establish nation-wide information networks.

The USDA-RDS Solar Outreach Program, by demonstrating that local interest in hands-on workshops is strong, led directly to establishing national training sessions through a Department of Energy Contract. The New Mexico Energy Extension Service of the Department of Energy has funded the Solar Sustenance Team to train three person teams from twenty different states to organize and manage solar greenhouse workshops. The teams contain one person with building/design experience, one with horticultural expertise and one with community mobilization skills. Hence, the three most important elements of the successful workshop are embodied in one team. The primary purpose of the training is to put the expertise where it belongs, at the local level. By having experienced trained personnel available locally, many of the problems in data collection and operator training can be avoided.

One primary obstacle to solar implementation which is slowly being overcome is the view that "solar is fine for the south or southwest but cannot pay back in areas of the country with less sunshine or colder weather." This view, still held by a majority of the citizenry, is possibly a result of inaccurate national media presentation which has given emphasis to very expensive solar systems. In a real sense, the only way to judge the economics of a solar application is dollars in (in materials and labor) and dollars out in energy saving. The dollars out will vary drastically depending upon conventional power costs in any given area. This can clearly be seen in a chart from a paper by D.C. Taff, R.B. Holdridge and John Wolfe shown below.

FUEL REDUCTION CONTRIBUTED BY AN ATTACHED SOLAR GREENHOUSE***

City	65 Degree Base	Solar Heat Produced by Greenhouse* (KW-hrs.)	Heat Loss of Greenhouse** (KW-hrs.)	Ratio of Heat Gain to Heat Loss	Fuel**** Reduction (percent)	Savings**** ($)
New York, NY	4871	5652	2007	2.8	32.1	324.85
Boston, MA	5634	5592	1856	3.0	28.5	227.90
Burlington, VT	7865	4476	2931	1.5	8.4	77.25
Philadelphia, PA	5251	5452	1548	3.5	32.0	206.91
Baltimore, MD	4654	4818	1414	3.4	43.5	156.58
Chicago, IL	6155	4993	2159	2.3	19.8	130.36
Springfield, IL	4561	5754	1821	3.2	37.0	173.05
Milwaukee, WI	7205	5965	2735	2.2	19.2	125.97
Denver, CO	6283	7897	1996	4.0	40.3	224.24
Dayton, OH	5597	4803	2042	2.4	21.1	99.40
Cincinnati, OH	4870	5003	1356	3.7	32.1	124.00
Duluth, MN	10000	6809	3968	1.7	12.2	------

* Energy available after transmission and reflection losses subtracted.

** Based on 55^{o} nighttime setback and materials as described in Table 1.

*** Dwelling is assumed to use 2.33 KW-hrs. per degree day (base 65). This quantity of heat is typical of an average U.S. home.

**** Value of energy is based on available electrical costs during January, 1976.

For example, in the model studies shown in the New York area the greenhouse saved $104.61 more than the unit located in Denver ($328.85 - 224.24) even though the Denver greenhouse produced 2,235 more KW-hrs. of solar heat. At a total cost of $889 the greenhouse pays back much faster in the northeast than in other parts of the country.

The future and potential of the solar greenhouse field is unlimited. Although many people are becoming aware of the concept, some of the most important sectors of the population have not been touched; bankers and builders being the most notable examples. The National news media, particularly television, has been conspicuously silent on low cost solar applications and does not seem interested in expanding presented objective information or equal time on the subject to the general public. The most encouraging signs of acceptance come from some government lending institutions, (such as Farmers Home), state tax rebate or deduction allowances (California, New Mexico) and from local media sources. Again, the onus falls to the local level for enthusiasm and support, it doesn't seem to come from the top down.

It is our opinion that the interest in solar greenhouses will grow at a faster rate than any other area of solar development, with the possible exception of water heaters. The systems will be adapted at all levels from the inexpensive retrofits, as were built in this project, to more elaborate totally integrated designs in new homes. The rate of implementation will be primarily determined by the number of successful examples in the field. Word-of-mouth, a neighbor's successful experience, is powerful testimony to the effectiveness of a solar system, and probably carries more weight with individual home owners than published reports or technical data. As an increasing number of solar greenhouses are built, models will emerge which meet the particular climatological economic and aesthetic needs of the local area.

The USDA-RDS Solar Outreach Project, through demonstrating the construction, operation and benefits of the solar greenhouse, through establishing networks and supporting already existing networks, achieved its primary goals.

APPENDIX

ENERGY AUDIT FOR AN ATTACHED SOLAR GREENHOUSE

PREPARED BY HARVEY LICHT RESOURCES FOR COMMUNITY ALTERNATIVES

Overview

Some analysis has already been conducted on the *economic* feasibility of the food and heat producing greenhouse.[1] To supplement this analysis, we have conducted some additional reviews of the *net energy effectiveness* of the greenhouse. These reviews are summarized in this section.

The reviews that we conducted take a more comprehensive look at greenhouse energetics—including a look at the energy costs of both construction and operation. They give us a more accurate picture of the total energy balance in a typical greenhouse. While the economic feasibility of the greenhouse may change rather quickly with changes in relative costs, the *energy cost analyses* discussed here will be accurate for a longer period—changing only with widespread changes in production technology.

In this section we will look at the results of *3* different types of analysis:

Annual Energy Analysis - The Balance Sheet: In which we *compare* the energy inputs and outputs required annually in a typical greenhouse, so as to identify whether it is operating at a relative *gain* or *loss*. We look at two different balance sheets—one focusing on the energy totals of both construction and operation, and the other focusing solely upon the energy totals involved in annual operation of the greenhouse.

Alternative Energy Consumption Analysis: If the greenhouse were not utilized, its outputs (food and heat) would have to come from some other source. In this part of the study, we identify the *energy cost* of securing these outputs from conventional sources. This energy cost can be considered an annual *savings in energy consumption* made possible by the use of the greenhouse. It gives us a clearer picture of *total* home greenhouse benefits.

Energy Breakeven Analysis: There is a relatively high initial energy cost involved in constructing the home greenhouse—energy tied up in the materials and labor needed to erect the structure. It is a *one-*

time cost, which can be 'amortized' by the continuing stream of energy benefits available during the life of the greenhouse. In this part of the study, we peform this longer term analysis of the energy costs and benefits which occur during the useful life of a typical home greenhouse. We identify the *breakeven point*—the point in time when initial energy costs are amortized—and review the *total energy surplus* available during the life of the greenhouse.

Annual Energy Analysis - The Balance Sheet

Introduction: Balance sheet analysis, where the different energy costs and energy gains of the greenhouse are totalled and compared, is the basic type of analysis needed in reviewing the effectiveness of our typical operation. It is analagous to the profit/loss statement of a business. From the balance sheet you can tell, at a glance, whether the greenhouse has produced, over the course of a year, a *net energy profit* or a *net energy loss*.

We compiled *2* different balance sheets. The first one covers *greenhouse operation*. In it we review the average annual energy costs and energy gains involved in operating a typical greenhouse. The second one covers *greenhouse construction and operation*. It is an expansion of the first sheet which includes the added energy costs of construction. This balance sheet gives a picture of energy inputs and outputs during the *first* year. The greenhouse operation balance sheet gives a picture of energy use during subsequent years. Both balance sheets focus upon a typical 10' x 16' structure erected in Albuquerque, NM.

We considered 6 different factors in putting together the balance sheets. They are described below.

Energy Inputs:

Construction Materials Energy: Significant energy went into the fabrication of materials used in the greenhouse. A true picture of the total energy used in greenhouse construction must include calculation of the process energy used to create construction materials. This energy total must include the power consumed at *all* stages of fabrication, from extraction to final product finishing.

Construction Labor: This includes an estimate of the total energy expended by human labor in erecting a typical greenhouse.

Production Materials Energy: Several different consumable materials are used in the continuing production of vegetables in the greenhouse. This factor includes an estimate of the energy needed to produce and obtain these materials.

Production Labor: This includes an estimate of the total energy expended by human labor in cultivating and harvesting a typical mix of greenhouse produce.

Energy Outputs:

Food Energy: This includes the total caloric value of a typical harvest of greenhouse produce.

Residential Space Heating Energy: This includes the total surplus heat energy available from a typical greenhouse for use in residential heating.

The results of our analysis are summarized in Figure A: *Energy Balance Sheet of Annual Greenhouse Operation*, and Figure B: *Energy Balance Sheet for Initial Year's Operation*. It should be clear, from inspection of the first sheet, that in any given year, the energy *gains* from the greenhouse far outweigh the operating energy costs. The residential space heating gains are by far the most important factor in this net energy profit, with food energy totals being relatively unimportant in the calculations.

Surprisingly enough, there is even a net energy profit in the balance sheet for the initial year. The heating energy available from the greenhouse is so great that even materials fabrication energy is small by comparison. This means that *the greenhouse will be operating at a net energy gain throughout all the years of its existence.*

Methods of Calculation: The different factors used on the balance sheet were calculated in the manner detailed below:

Calculation of Greenhouse Output Energies:

Residential Heating: For the typical greenhouse application in northern New Mexico, surplus heat will be used for residential heating during three seasons of the year. From earlier on-site measurements, we have 3-season averages of surplus heat days from a typical greenhouse. Simple calculation of seasonal energy totals can be made from these figures and the number of days in each season. A summary of these figures is included in Figure C: *Space Heating Totals.*

Food Energy Values: The bulk caloric value of greenhouse production is used to measure the food energy output. To arrive at this figure, we first estimated the amounts of a typical yearly produce harvest from a greenhouse. Next, we identified average caloric values for the different items produced, per unit of product. Finally, we calculated the total food energy value of the annual crop. A summary of these figures is included in Figure D: *Food Energy Totals.*

Calculation of Greenhouse Input Energies:

Construction Labor Input: We used the following approach to calculate the human energy input to the greenhouse. First, we calculated the number of person hours needed to construct a typical 10' x 16' greenhouse. Next, we identified a figure estimating how much energy is expended by a person working at a moderate pace. Finally, we calculated the total labor energy required in construction.

Our labor estimate included several activities beyond the actual erection of the greenhouse structure. Significant time was spent collecting native materials used in the greenhouse—soils and rocks. All these activities are covered in the estimate. See Figure E: *Labor Energy Totals.*

Construction Materials Fabrication Energy: We used the following approach to calculate the energy needed to create the materials used in greenhouse construction. First, we prepared a listing of materials required for greenhouse construction. Next, we identified the direct energy input required in the fabrication of different materials, per unit of each material. Finally, we calculated the energy embodied in each of the materials. A summary of these figures is included in Figure F: *Construction Materials Energy Totals.*

Operational Labor Input: These energy totals were calculated in a manner similar to construction labor totals. First, estimates were created of the average number of person-hours needed *annually* to cultivate and produce a crop. Next, we used estimates of average hourly energy consumed hourly in moderate labor in calculating the total human energy expended annually. These labor figures cover the time needed for preparing, planting, cultivating, and harvesting a typical greenhouse crop. A summary of these figures is included in Figure E: *Labor Energy Totals.*

Operational Materials Input: Three materials are consumed on an ongoing basis once the greenhouse is erected, and production begins. Fertilizer, pesticides, and water are needed in the production cycle. To calculate the total energy cost of these materials, we first estimated the amounts that are consumed during a typical year. For the water, the only energy cost is the energy needed to pump the water to the site. We identified the amount of energy required to drive a typical domestic water pump to deliver the water. For the fertilizer and pesticides, we used a procedure similar to that used in calculating construction materials. We took existing estimates of fabrication energy, and added on the energy necessary to transport the fertilizer and pesticides from the place of manufacture to the point of final use. See Figure G: *Operational Materials Energy Totals.*

The use of organic farming techniques, which reduce the number of manufactured materials used in production, can further reduce these energy costs. All estimates were based upon non-organic techniques.

Sources of Estimates:

Two major studies were used as the source of our estimates on construction materials energy.[2] Both were based upon a report prepared by the Center for Advanced Computation at the University of Illinois—the premier study of energy use in U.S. manufacturing.[3]

Both the studies that were used contain energy totals which go no farther than the point of fabrication. Energy needed to *transport* the materials to the site of final use is not included. We performed several calculations to derive these transport figures, and used the latest national average energy consumption rates for truck transportation.[4]

In calculating construction materials energy, we used the most specific product figures available. In some cases, figures were not available for the specific products that we used. In these instances more general product category figures were employed. For example, no figures were available specifically for 50 gallon drums, so instead, figures for general sheet metal products were used.

The figures used in materials calculations are the most widely cited ones focusing on the U.S. manufacturing scene. They do however, have their limitations. They do not include *human* labor energy inputs to production. A critique of the figures, with a discussion of their limitations, can be found in one of the studies.[5] For purposes of our analysis, however, these limitations are not overwhelming, and we are confident that they represent an accurate estimate of the totals involved.

For food value estimates, we consulted two nutritional reference sources.[6] These provided figures on food caloric value developed by the U.S. Department of Agriculture. Estimates of human energy expenditures came from another nutrition reference.[7] Estimates of transport distances came from a standard reference atlas.[8]

Alternative Energy Consumption Analysis

The balance sheet analysis of the greenhouse, described above, does not, by itself, show the full energy picture of greenhouse use. To get a more complete picture, it is important to look at the alternative energy consumption story, i.e., what a family's energy consumption would be if the greenhouse's outputs were *not* available to them. For example, if vegetables were not available from the greenhouse, they would have to come from somewhere else—probably at a greater energy cost.

By looking at the total energy needed to get greenhouse outputs from other sources, we can get an analysis of whether the greenhouse can significantly reduce the energy required to support a family. The energy costs of securing heat and food from conventional sources can be considered *energy savings* made possible by the greenhouse. As such, they can be added into the energy gains side of the balance sheet developed in the last section, as part of the total energy benefit of greenhouse use. When this is done, the balance sheet becomes something other than a chart of actual energy use—it becomes a tally sheet for all *energy costs and benefits* which can be attributed to greenhouse use. This type of analysis is identical to *economic cost/benefit analysis*, except that we are looking at energy costs instead of economic costs.

The results of our alternative energy cost analysis is summarized in Figure H: *Total Energy Costs and Benefits.* It should be noted that it is more than just doubling of the energy gains side of the annual balance sheet. The energy costs for the food from conventional sources are significantly higher than the energy cost of the same

produce grown in the greenhouse. Food is grown with a greater energy efficiency in the greenhouse, and does not require energy consumptive processing and transportation between producer and final user.

We calculated the energy cost of produce from conventional sources in the following manner. First, we identified a national average figure for the use of energy in the production of fresh vegetables.[9] This figure was in the form of BTU's/Acre under cultivation. Next, we estimated the size of the greenhouse production area, and calculated what the total production energy of a typical yield would be under commercial production. Finally, we calculated the transportation energy needed in much the same way as for construction materials.

We did not include the energy cost of fuel energy extraction and transport in our totals of alternative energy cost. We included only the total heating value saved. A number of different fuels could have been used, each with a different transport cost; so the decision was made to overlook these costs for simplicity's sake.

Energy Breakeven Analysis

We conducted one final type of analysis of greenhouse energetics. In this analysis we looked at the *net energy savings* available and the *energy outputs* available from a typical greenhouse over a 10-year period. Next, we looked at the *total energy utilized* in constructing the greenhouse and operating it over a 10-year period. Finally, we plotted the two different totals to find the point in time where the energy inputs equal energy savings and outputs. This point is the *energy breakeven* point for greenhouse operation.

As mentioned earlier, there is a fairly high initial energy cost involved in constructing the home greenhouse—energy tied up primarily in the materials needed to erect the structure. This *breakeven analysis* of the greenhouse identifies the point where this cost is met by resultant savings in consumption of non-renewable energy. At all points after the breakeven point, the greenhouse is operating at a *net energy profit*.

This type of analysis is a good adjunct to other types of analysis, including financial breakeven analysis (analysis of when the *financial* costs of the greenhouse are counterbalanced by the financial benefits). Insofar as the financial picture doesn't actually represent the true energy picture—because of things like price regulation of energy products—the energy breakeven analysis shows a clearer picture of true greenhouse cost.

The results of the breakeven analysis are summarized in Figure I and Figure J. The first chart plots the results of annual energy analyses over a ten year period. The second chart adds in the results of the alternative energy analysis—and shows how energy savings help accelerate the achievement of breakeven. Both cards indicate *achievement of energy breakeven within the first year.*

NOTES ON ENERGY AUDIT
BY BILL YANDA

The heat energy output of the greenhouse used in the study is for solar and degree day conditions in Albuquerque, New Mexico. In more severe climates the Residential Heating Value would be lower; in less severe climates, higher. It is suggested that in the contiguous United States severe solar and degree day conditions won't reduce the yearly performance by more than 40 percent. Hence the greenhouse will operate at a net energy surplus everywhere in the United States except Alaska. [65,412,239 Albuquerque surplus × .40 (worst case reduction) = -26,164,895 + 65,412,239 or + 39,247,343 (worst case surplus)] .

A disappointing outcome of the energy audit (for this author) was that it revealed the total food output of the greenhouse as an insignificant fraction (113/65,312,126 BTU) The reason is, of course, in the type of food the greenhouse produces, i.e., low caloric content vegetables. A more appropriate number is found in the energy *saved* by home production. (Yearly food energy savings - 182,193) As noted in the audit, energy cost factors for conventional agricultural techniques in fertilizing and insect control were used. In reality low energy techniques (manure fertilizers, organic pesticides) are generally applied in attached solar greenhouses and will result in higher yearly food energy savings.

To consider the energy audit alone as the indicator of the advantages of a solar greenhouse would be short-sighted. A complete picture would include the nutritional and taste benefits of home-grown vegetables; the former can be examined analytically, the latter cannot.

FIG. A

ENERGY BALANCE SHEET FOR INITIAL YEAR'S OPERATION

Energy Input	Energy Output
Labor for Operation: 267.25 BTU	Produce Food Value: 113.67 BTU
Operating Consumables: 26,085.72 BTU	Residential Heating Value: 65,412,126 BTU
Annual Energy Input: 26,352.97 BTU	Annual Energy Output: 65,412,239.67 BTU

Annual Net Surplus: 65,385,886.7 BTU

FIG. B

ENERGY BALANCE SHEET OF ANNUAL GREENHOUSE OPERATION

Energy Input	Energy Output
Construction Labor Input: 214.15 BTU	Produce Food Value: 113.67 BTU
Construction Materials Energy: 37,783,825 BTU	Residential Heating Value: 65,412.126 BTU
Operational Labor Input: 267.25 BTU	
Operating Consumables: 26,085.72 BTU	
Initial Year's Energy Input: 37,810,392.12 BTU	Annual Energy Output: 65,412,239.67 BTU

Net Energy Surplus: 27,601,847.55 BTU

FIG. C

SPACE HEATING TOTALS

Season	Length	Daily Energy	Total Energy
Autumn	90 days	252,212 BTU	22,699,080 BTU
Winter	90 days	151,464 BTU	13,631,760 BTU
Spring	93 days	312,702 BTU	29,081,286 BTU

Total = 65,412,126 BTU

FIG. D

FOOD ENERGY TOTALS

Item	Quantity	Food Value	Input Energy
Beans	12 lbs.	720 cal = 2.855 BTU	14.275 BTU
Cabbage	75 lbs.	9545 cal = 37.853 BTU	189.25 BTU
Carrots	6 lbs.	1200 cal = 4.759 BTU	23.795 BTU
Cucumbers	12 lbs.	818 cal = 3.244 BTU	16.22 BTU
Eggplant	20 lbs.	1364 cal = 5.409 BTU	27.045 BTU
Leafy Greens	60 lbs.	2727 cal = 10.814 BTU	54.07 BTU
Squash	12 lbs.	2280 cal = 9.042 BTU	45.21 BTU
Onion Family	8 lbs.	1636 cal = 6.488 BTU	32.44 BTU
Peas	8 lbs.	2464 cal = 9.771 BTU	48.855 BTU
Peppers	6 lbs.	682 cal = 2.705 BTU	13.525 BTU
Radishes	5 lbs.	500 cal = 1.983 BTU	9.915 BTU
Tomatoes	52 lbs.	4727 cal = 18.746 BTU	93.73 BTU

FIG. E

LABOR ENERGY TOTALS

Activity	Time	Total Energy
Annual Operation:	312 Person-hrs.	67,392 cals = 267.25 BTU
Construction of G-H:	250 Person-hrs.	54,000 cals = 214.15 BTU
Collecting Native Materials	8 Person-hrs.	1,728 cals = 6.85 BTU

Total 488.25 BTU

FIG. F
CONSTRUCTION MATERIALS ENERGY TOTALS

Material	Quantity	Total Energy
Styrene Beadboard	5 - 4 × 8 sheets	753,164 BTU
Portland Cement	3 - 94 lb. sacks	1,157,083 BTU
Concrete Sand	6 ft.^{3}	25,974 BTU
Rebar	72' × 3/8"	192,895 BTU
Anchor Bolts	10	64,127 BTU
Dressed Lumber	2" × 4" × 396'	1,077,180 BTU
Corr. Steel Sheet	4 - 2' × 8'	2,863,246 BTU
Insulation	32' × 2' × 3.5"	402,046 BTU
Poly Film	70'^{2} x 6 mil	107,298 BTU
Gypsum Wallboard	2 - 4' × 8'	528,458 BTU
Fiberboard	3 - 4' × 8'	684,506 BTU
Stucco Mesh	30' - (3' wide)	392,915 BTU
Masonry Cement	2 - 94 lb. sacks	1,034,393 BTU
No. 8 Sand	6 ft.^{3}	22,121 BTU
Colored Stucco	1 - 100 lb. sack	312,911 BTU
Insulation	80 ft.^{2}	501,803 BTU
Poly Film	80 ft.^{2}	122,622 BTU
Gypsum Wallboard	3 - 4' × 8'	792,688 BTU
Corr. Lascolite	2 - 10' × 4'	1,468,991 BTU
Flat Lascolite	1 - 4' × 50' roll	4,590,597 BTU
Poly Tape	1 - 150' roll	9,263 BTU
Wooden Lath	1/4" × 1-1/2" × 200'	4,526 BTU
Poly Film	250 ft.^{2}	383,199 BTU
Closure Strips	90' - 1/2" round	101,189 BTU
Plywood	1 - 4' × 8' × 1/2"	228,469 BTU
Storm Door	1	600,872 BTU
Gal. Flashing	40' × 6"	1,590,926 BTU
Steel Fasteners	25 lbs. (assorted)	650,891 BTU
Aluminum Nails	150 ct.	30,283 BTU
Wallboard Compound	1 - 25 lb. sack	97,445 BTU
Rafter Hangers	5 ct.	65,600 BTU
Caulk	9 tubes	830,260 BTU
Paint	2.5 Gals.	1,031,999 BTU
Trim Boards	1" × 6" × 60'	21,766 BTU
Steel Drums	6 - 55 gal.	12,693,135 BTU
Cinder Block	80 blocks	2,348,984 BTU

FIG. G
OPERATIONAL MATERIALS ENERGY TOTALS

Material

Fertilizer
- National average use per acre of fresh vegetables: 5,518,000 BTU - equiv. of feet per acre
- Total acreage: .00330579 acres
- Total energy in fertilizer: 18,241.35 BTU

Pesticide
- National average use per acre of fresh vegetables: 636,000 BTU of pesticide per acre
- Total acreage: .00330579 acres
- Total energy in pesticides: 2102.48 BTU

Material

Water
- Annual water need: 6.2 gals/sq.' × 144 = 892.8 gal/yr.
- Pump draws 24.7 g.p.min. at 2,793 watts
- Annual energy use: 1.68278 KWH = 5741.89 BTU

Total: 26,085.72 BTU/year

FIG. H
TOTAL ENERGY COSTS & BENEFITS

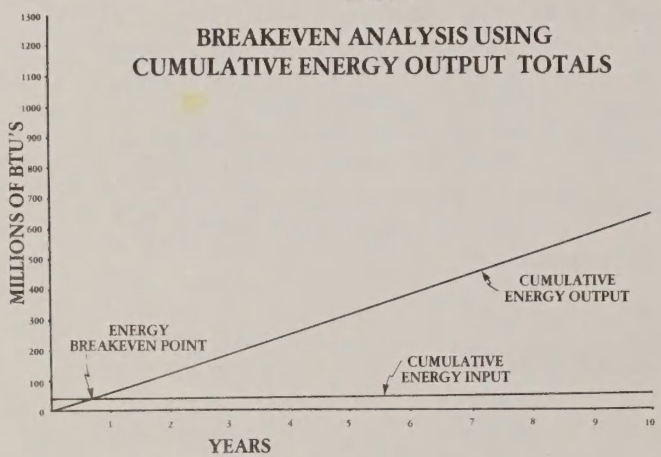
Energy Costs

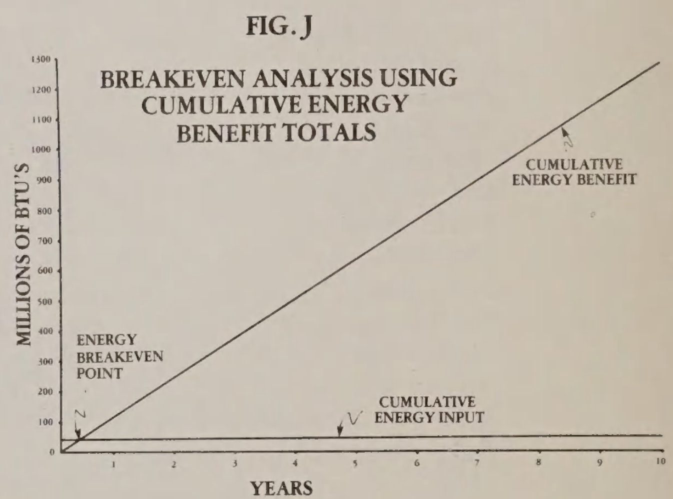
Annual energy input: 26,352.97 BTU

Energy Benefits

Annual food & heat outputs: 65,412,239.67 BTU
Additional fuel savings: 65,412,126 BTU
Food energy savings: 182,193 BTU

Net energy benefit: 130,980,205.70 BTU





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